COMMENTS ON THE RECENT DYNAMICS OF SCREE SLOPES IN THE CZECH MIDDLE MOUNTAINS

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Scree slopes have been actually long recognized as significant landforms in a landscape, which represent the indicators of palaeogeographical development of a territory on one hand, and the specific recent environment on the other. The origin and primary development of these landforms was traditionally related to the Last Glacial, resp. Dansgaard-Oeschger cycles, however, the progress in geomorphologic research of scree slopes during last few decades indicated, that these might have evolved continuously during the Holocene period. Our research, which was carried out in the Czech Middle Mountains in north-western Czechia was focused on evidences of the recent dynamics of scree slopes and their environmental change. Dendrogeomorphologic and dendrochronologic analyses showed the evidences of rock-fall, i.e. continuous formation of scree, at least 15 years back. Moreover, sedimentologic analyses of clast size, distribution, and shallow profiles indicated the probable climatic multifactor influence taking part on recent intensive dynamics of scree slopes. Overall results of the research than contribute to the concepts of environmental changes of the Quaternary rocky slope mantles.

Key words: scree slope, environmental change, dendrogeomorphology, the Holocene, the Czech Middle Mountains

1. INTRODUCTION

As the periglacial record in Central Europe has become a well distinguished and almost certain issue for many geomorphologists, only in past few decades they recognized also the possibilities and effects of recent environmental changes of periglacial landforms. One group of such landforms are so called slope covers, which are according to PAWELEC (2006) all types of sediments that occur on and at the foot of slopes as results of direct deposition, or redeposition. Among these landforms, especially scree slopes (or rock-mantled slopes) have deserved a top attention thanks to the fact, that their geomorphologic and consecutively the microclimatic conditions represent a unique environment for many glacial fauna and flora species (ZACHARDA 2000, GUDE et al. 2003a). Therefore, much has been done about microclimatologic measurements (e.g. KUBÁT 1999), research of possible permafrost-like conditions using geophysical tools (GUDE et al. 2003a and 2003b; SCHROTT, PFEFFER and MÖSELER 2000), and biogeographical and ecological observations (MÖSELER and MOLENDA eds. 1999, ZACHARDA 2000) however, the process-oriented geomorphologic research has only lately found its solid position in the issue.

This increasing importance of geomorphologic research on scree slopes emerged from the better recognition of the geomorphologic heart of their environment, i.e. the existence of thick layer of blocks with an open-void system (GUDE et al. 2003a). This fact then led to consideration of the age, long-term dynamics and possible recent changes of this system due to manifold geomorphologic processes (for an overview see e.g. CÍLEK 2000, RAŠKA, in press). The attention has been paid especially to climatic factors; Pawelec (2006) assessed the palaeoclimatic significance of slope covers, HÉTU and GRAY (2000) occupied the issue of frost-thaw cycles and niveo-aeolian factors, the correlation between tectonic movements and climate-controlled variations of scree production was analysed by HALES and ROERING (2005). Furthermore, the biotic factors have been newly appreciated. GOVERS and POESEN (1998) studied the effect of animal trampling on the dynamics of screes, intense research has been devoted to the effect of vegetation in the postglacial environmental change as well (e.g. HÉTU and GRAY 2000). If we consider scree slopes as a patch inside the matrix of forest vegetation, the biogeomorphologic approach seems to be very efficient in discovering the recent changes of these landforms. This was shown for

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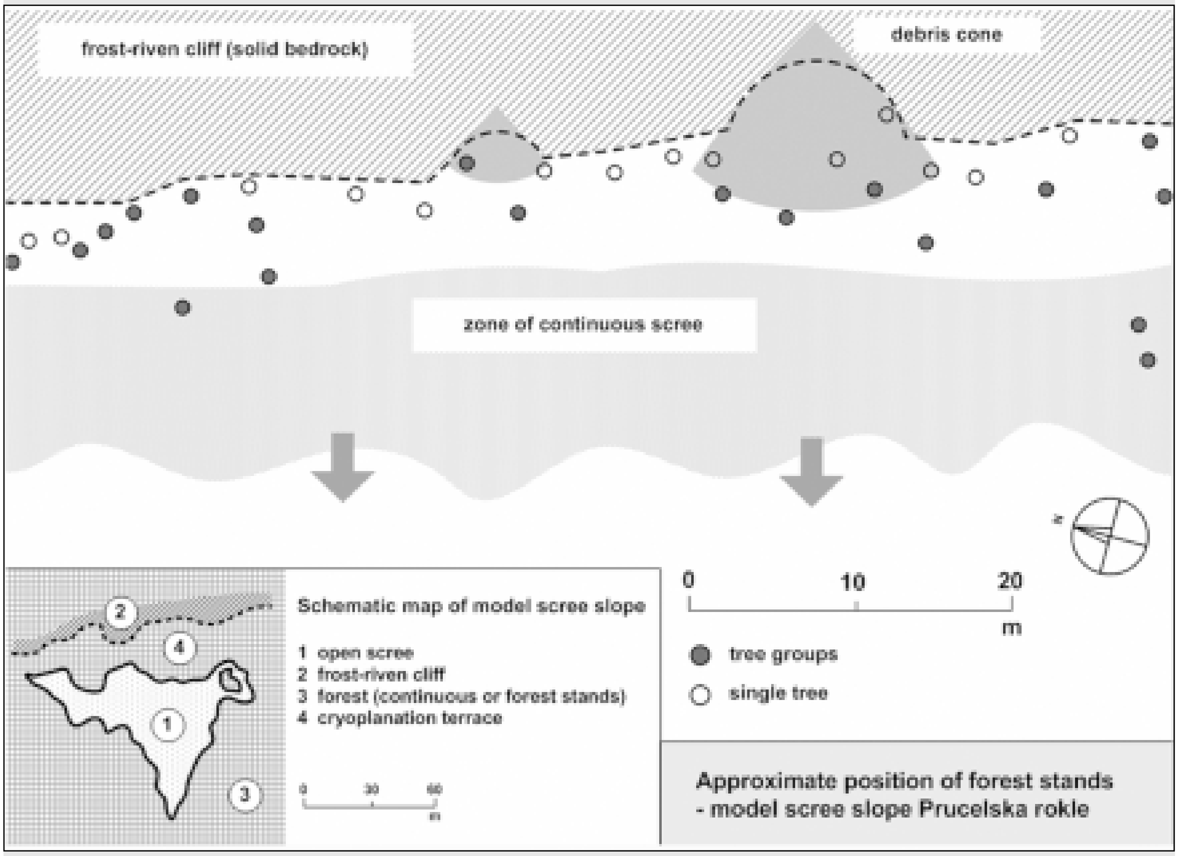

Fig. 1 Schematic plan of a study site

instance by M. Stoffel (STOFFEL 2005, STOFFEL and PERRET 2006) who used dendrogeomorphologic methods to analyse the temporal and spatial dimensions of rock-fall activity, or by PHILLIPS and MARION (2006) who assessed the role of trees in physical changes of regolith and soil character.

If we conclude, the variety of methodical approaches has been applied in a study of scree slopes in different areas and primarily based on regional and only partially on local scale. However, similar studies for the areas of the Bohemian Upland are almost lacking and if these appear, they usually deal with an inventory or characteristics of scree slopes in regional scale (e.g. KIRCHNER, CÍLEK and MÁČKA 2001) and only rarely in local scale or a scale of a single scree slope site. At the same time, most of screes (and ice screes) in Czechia are biogeographically significant and therefore it is necessary to study the stability of their environment. Next reason to study the recent dynamics of scree slopes is that these are often considered as one type of indirect indicator of the Pleistocene permafrost (CZUDEK 2005a and 2005b). Nevertheless, if their intensive continuous development during the Holocene period will be proved, their role as indicator would be much more ambiguous.

The general objective of the present study was to analyse the recent intensity of scree slope dynamics using dendrogeomorphologic and sedimentologic methods. This dynamics can be seen as a system of four main processes: a) accumulation of new material, b) transformation and c) translocation of this material, and d) denudation of scree material. The concrete aims of the study were to (i) assess the role of vegetation in accumulation and denudation of scree material, (ii) to evaluate the potential of selected relative and absolute dating methods of the rock-fall (accumulation) activity in the upper part of scree slopes, and (iii) to verify the application of sedimentologic methods in a study of vegetation-controlled and climate-controlled scree slope processes.

2. Methods and Material

2.1 Study site

The study presented was performed at the site of Průčelská rokle (gorge), which is located in the Czech Middle Mountains (Böhmisches Mittelgebirge; NW Czechia). The Czech Middle Mountains is a volcano-sedimentary complex of the Tertiary age, which evolved in the tectonic-volcanic zone of the Krušné hory rift structure (CAJZ et al. 2005). Neovulcanites of the area are mostly represented by different types of basaltic and trachytic rocks which were in great extent eroded by the river of Elbe and its tributaries. This erosion and denudation exposed the Mesozoic and, in deep river beds, also the Palaeozoic rocks.

The study area is built by neovulcanites of primarily basaltic type, which are covered with vulcanoclastics and various slope sediments. The Průčelská rokle (gorge) is formed by small subsequent tributary of the Labe river - the Průčelský potok brook – and is about 450-500 m deep (from highest lateral ridges to the bed). The formation of Průčelský potok brook as well as of other Elbe river tributaries was dated by several authors to the Upper Pleistocene (e.g. KRÁL 1966, NĚMEČEK 1972). The intense erosion then continued during the whole Holocene and caused concurrent rejuvenation of slopes. These are covered by 10 open scree accumulations and many other covered with vegetation. The research was performed at selected site shown in the **Fig 1**.

The study scree is about 70 m long (downward the slope) and 60 m wide, and is formed by clasts of approximately 5 cm to more than 2 m in diameter. In the upper part of the scree, there is a frost-riven cliff (maximal exaggeration of continuous rock wall is ca 20 m) and cryoplanation terrace covered by single trees and groups of trees. The bottom part of the scree continuously transforms into the scree and boulder streams penetrating into the forest sites represented by deciduous trees (esp. assoc. *Fagion sylvaticae*). Recent geomorphologic processes at the site comprise especially rock-falls which were eye witnessed, sliding due to manifold climatic, hydrologic and biotic factors.

2.2 Methods

The bioprotective role of vegetation has been analysed using biogeomorphologic and dendrogeomorphologic methods, which were widely discussed by Naylor et al. (NAYLOR, VILES and CARTER 2002) or STOFFEL and PERRET (2006). Firstly, a mapping at the cryoplanation terrace of the site was performed focusing on location and identification of single trees and groups of trees. Then the effect on scree was determined in each of these. The types of effects were assigned into four categories classified according to our former observations and verified during the contemporary research. To assess the temporal dimension in rock-fall activity, i.e. accumulation of new material, we selected sample trees to identify the size, orientation and height of scars caused by rock-falls. Furthermore, we took two sample disc stems of trees to enable the absolute dating of rock-fall impacts using tree ring analyses. To verify the probability of spatio-temporal variations in rock-fall activity at frost-riven cliff, the Schmidt hammer test was performed using the hammer NR type. The potential and limits of this test was summarized by GOUDIE (2006). We have measured at 19 sections of the frost-riven cliff to find out the relative age of surface exposed to rock-fall activity. The reliability of test at the study site is supported by homogenous petrographic conditions of the frost-riven cliff, and identical number of hits (10) at equal distances (5 m). The results, which are shown in table 1, were analysed by mean of basic statistical tools (standard deviation, coefficient of variation, etc.).

Next method used in scope of our research aims, was sedimentological measurement at selected logs, and clast shape and size analyses of specific landforms, which were supposed to be the results of frost-controlled sliding. These forms are referred by HÉTU and GRAY (2000) as frost coated clast flows (FCCF). Sliding of the material, which forms the landforms with concave channel leading into the terminal lobe, is explained by thin layer of ice on the surface of clasts. At these sites of supposed FCCFs we constructed plans and profiles, and measured the spatial distribution of different clast size to verify the frost-controlled sorting.

3. Results

At the cryoplanation terrace, we mapped 14 single trees and 19 groups of trees. Our measurements prove that single trees are usually located nearer to the frost-riven cliff in comparison with tree groups. This can be due to large rock-fall clasts which have higher speed and reach longer distances and therefore usually do not hit the trees immediately next to the frost-riven cliff. Contrarily, it seems that trees located in longer distance from the cliff might have been more often impacted by large and fast rock-fall clasts dividing their trunks. Furthermore, trees in longer distance from the cliff are represented by different species, more suitable to these injuries and deformations of trunks.

Types of effects assigned to single trees and tree groups can be divided into four main categories: (i) dam-like effect (a broken displaced trunk retaining scree), (ii) halt effect (a stable trunk capturing large boulders, (iii) chaotic bouncing effect, and (iv) weathering effect (biochemical effect of woody debris and fallen leafs). The most often is chaotic bouncing effect and halt effect, followed by weathering effect in the ecotone area of the study scree slope, and finally the dam-like effect. This order of effects frequency was furthermore verified by evidences of impacts on trees. As referred by PERRET, STOFFEL and KEINHOLZ (2006) or STOFFEL (2005), falling, rolling, or bouncing rock fragments can injure single trees or their groups by breaking, tilting or scarring stems. All of these types of effects occur at our study site, though the most often are scars on trunks (i.e. probable results of chaotic bouncing). The reason is that while breaking or tilting is caused by large clasts, scars can be caused by relatively small clasts which are more frequent in recent rock-fall activity. However, if we look at the **Fig. 2**, we can observe that scars are oriented not only upwards the slope (i.e. toward frost-riven cliff), but also downwards. This indicates that tilting or rotation occurs too at the study site.

Moreover, several cases of broken or displaced trees were observed which proves falling of larger clasts. The analysis of sample stem disks documented the existence of rock-fall at least 18 years back. Six scars on tree-rings were detected on the first sample stem disc (the oldest one 18 y BP), and seven on the second disc (11 y BP).

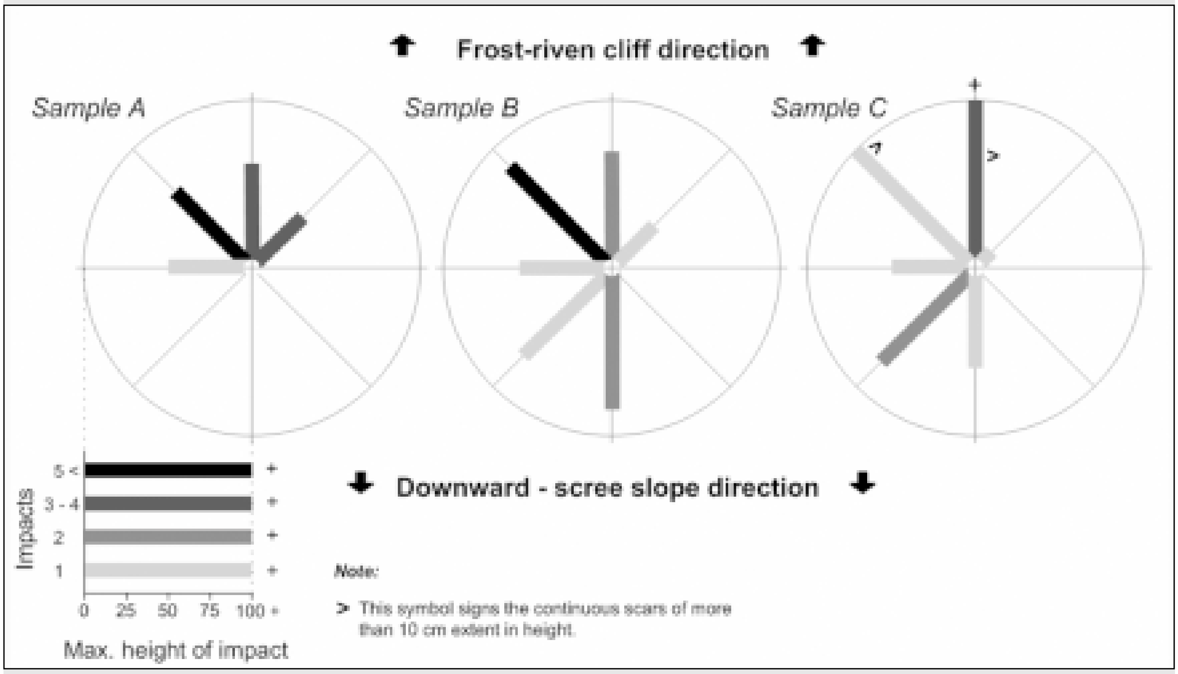

Fig. 2 Orientation and frequency of impact scars on sample tree trunks

Schmidt hammer measurements indicate high spatio-temporal variability in rock-fall at the site. The highest R values reached 45 in average at a single sampling sequence, whilst the minimal R values fell under 25. Recognizing these variances we tried to correlate the R values with maximum and minimum clast sizes below each sampling sequence. However, a small number of measured clasts and intense dynamics of these below the frost-riven cliff did not provide the sufficient results to evidence the correlation.

Sedimentologic measurements of selected logs and FCCF-like landforms showed the diversity of scree slope and existing horizontal and vertical shifts of clasts. The intensity of vertical shift was analysed by measurements on 50 logs, while at each one size of clasts (three axes) in three superposable layers was measured. This analysis indicates, that there is a distinct dependence of sizes in these layers, which can be expressed by vertical shift of smaller clasts under the larger ones. However, the smaller is a size of the surface clast, the more similar is a size of the underlying one (the regression equation for x - surface clast size and y – underlying clast size correlation is: $y = 0.338x+3.6894$) (cf. RAŠKA, in press). The inverse superposition conditions occur only where young weathered material sli-

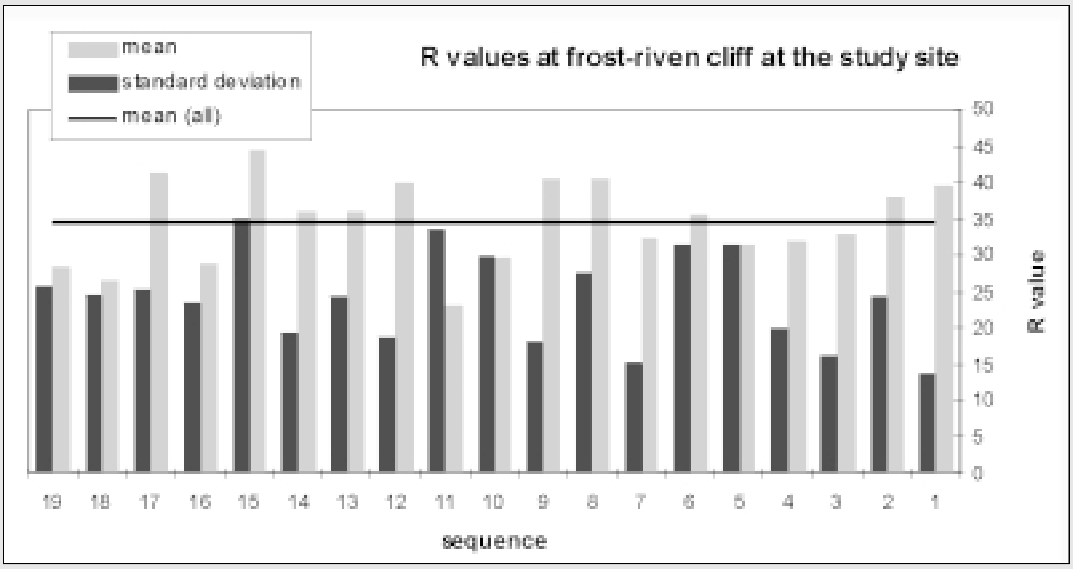

Fig. 3 Results of Schmidt hammer NR test at the frost-riven cliff

des over the older layer of scree, e.g. on FCCF-like landforms. When analyzing the FCCF-like landforms, the existence of size sorting ascribable to frost-controlled sliding was detected. The landform was divided into three sections (erosive channel, transitional zone, and terminal lobe), while the size of clasts as well as size homogeneity increased towards the terminal lobe.

4. Discussion

The main focus of the study presented was to analyse the probable occurrence and intensity of recent dynamics and environmental change of scree slopes in a non-Alpine environment. The results achieved indicate that the study site is exposed to relatively intense geomorphic processes causing its consecutive development and transformation. Among these processes rock-falling and sliding due to climatic and biotic factors play a significant role. These processes are considered as prevailingly scree-forming and were documented using dendrochronologic methods for at least last 18 years.

All these results are in agreement with findings by PERRET, STOFFEL and KEINHOLZ (2006) that have showed the significance of climate-controlled variations of recent scree production. Notwithstanding, it has to be said that temporal analyses of rock-fall activity next to frost-riven cliffs are limited because of several factors. Firstly, these are specific lithologic and relief conditions which limit the average age of trees. Secondly, if there are any of old age, these cannot be chopped down and analysed, since the study site is a part of the Protected landscape area Czech Middle Mountains. Thus, we could analyse only young trees, which were displaced recently to enable an efficient tree-ring based dating of impacts.

Contrarily, since the environmental change of scree slopes is usually represented by expanding forest sites, we analysed the role of single trees and tree groups (resp. forest sites) on above mentioned geomorphic processes. The effect of chaotic bouncing seems to be the major one thanks to relatively small clasts falling down from the frost-riven cliff. Nevertheless, other effects such as dam-like effect, or halt effect also occur which document the complexity of environmental change of scree slopes. Moreover, the role of vegetation seems to be an important factor in a disintegration of frost-riven cliffs conditioning the rock-falling processes.

Besides dendrogeomorphologic methods, sedimentologic measurements showed the evidences of both vertical and horizontal movements of clasts. The measurements of 50 logs showed the principles of superposition of scree material (cf. POESEN and LAVEE 1994, GOVERS and POESEN 1998). The results of FCCF-like landforms analyses indicate that these were actually created by frost-controlled sliding, however, our measurements were performed during the summer and

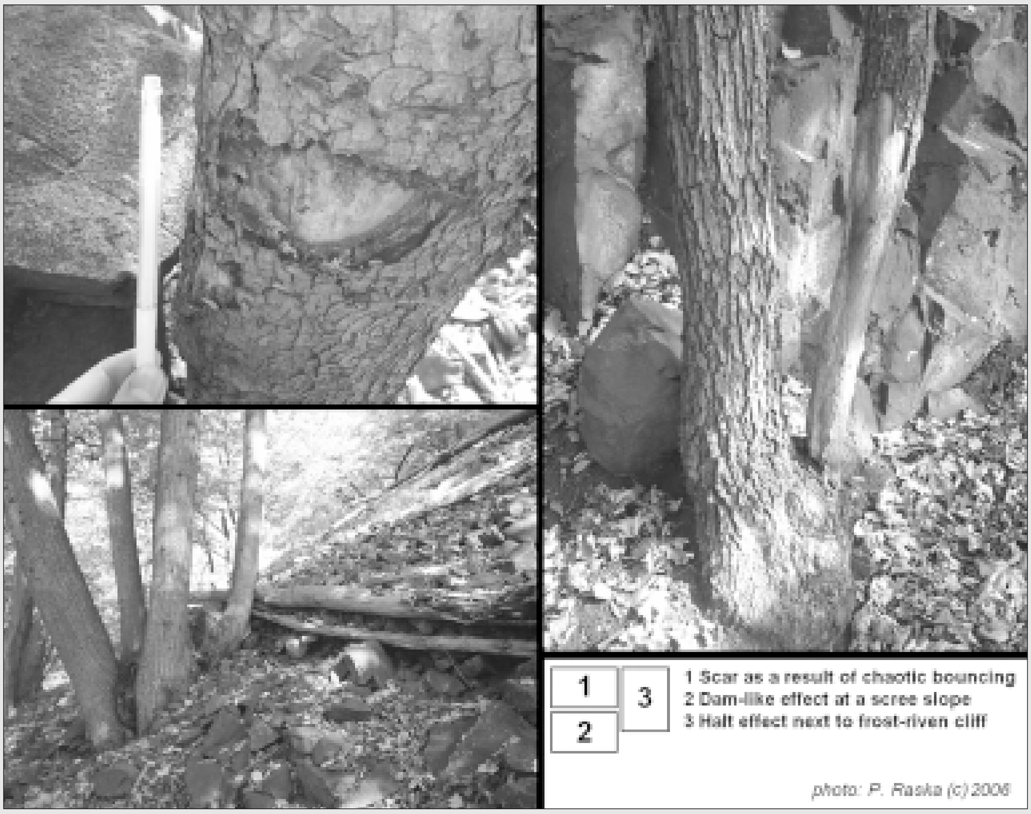

Fig. 4 Selected types of dendrogeomorphologic effects of trees at the study site

autumn period and therefore, the dynamics of these landforms should be further monitored during the winter months to enable the final conclusion about the existence of recent frost-controlled processes in mid-altitude highlands.

5. Conclusions

The results of this study can be summarized in the following conclusions:

(i) Vegetation plays a significant role in the environmental change of scree slopes considering its effects in geomorphic processes, such as rock-falling, sliding and denudation of scree material. In relation to rock-falling, vegetation (esp. roots) causes the disintegration of frost-riven cliffs (i.e. intensify rock-fall activity) on one hand, and represent a barrier of free movement of rock-falls on the other.

(ii) Dendrogeomorphologic, resp. dendrochronologic analyses (as referred e.g. by PERRET, STOFFEL and KEINHOLZ 2006, or NAYLOR, VILES and CARTER 2002) have large potential to provide detailed and various results to assess spatio-temporal variations of rock-fall processes, but this potential can be degraded by specific geomorphic and edaphic conditions at sites being studied. Schmidt hammer test is also an efficient tool to assess the rock-fall variances, but we should mention, that it can be applied only in lithologically homogenous environment of a single study site.

(iii) Sedimentologic methods used in scope of our research brought many results suggesting the role of climate-controlled transformations of scree slopes. Nevertheless, these methods have to be supported with other results of multitemporal measurements and microclimatic observations at a similar site to enable the final conclusion.

(iv) Altogether, this study has provided clear evidences of recent geomorphologic and environmental evolution of scree slopes. This means that recent scree slopes might have been formed continuously since the Upper Pleistocene and they are subject to consecutive polygenetic environmental change (cf. FRENCH 2007, CZUDEK 2005a). Future research should be therefore focused on long-term analyses of geomorphic processes and correlation of these with climatic and other data sets to enable the palaeogeographical reconstruction of scree slopes, and modelling of their future environmental change under different factors.

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